Polar Geosci, **11**, 239–248, 1998

RADIOCARBON AND THERMOLUMINESCENCE AGES IN THE MT. RIISER-LARSEN AREA, ENDERBY LAND, EAST ANTARCTICA

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Abstract: Varved organic clay (Richardson Clay) and thin coatings of calcite attached to rocks within thick till deposits (Tula Till) in the Mt Riiser-Larsen area, East Antarctica, were dated by accelerator mass spectrometry (AMS) radiocarbon and thermoluminescence (TL) dating AMS ^{14}C ages corrected by the $\delta^{13}C$ values in this study are 40250 ± 1200 y BP for the varved organic clay and 42570 ± 670 y BP for the calcite samples Although there is a possibility that these ages might be too young due to contamination by younger carbon or other factors, it seems hard to regard the true age of crystallization of the calcite as much older than the Last Interglacial Stage from the provisional result of TL dating In East Antarctica, ice thickness and extent during the Last Glacial Stage is assumed to have been very much less than was earlier hypothesized, and the thick glacial deposits in the Mt Riiser-Larsen area have been supposed to be a correlative of the thick late-Pliocene deposits in the Transantarctic mountains and the Prince Charles mountains The result of this study, however, suggests that in a region like the Mt Riiser-Larsen area where ice comes mainly from the coastal area around the Napier mountains, the possibility of a re-advance of the ice sheet and/or deposition of thick glacial tills during the late-Pleistocene should be taken into account

key words AMS ^{14}C age, TL dating, East Antarctica, Richardson Clay, till deposits

1. Introduction

In recent years, knowledge of the late-Cenozoic glacial history of Antarctica has been increasing. Review articles by WEBB (1990, 1991), BARTEK *et al.* (1991), DENTON *et al.* (1991) and MORIWAKI *et al.* (1992b) give overviews of the history and make various problems clear. As a result we can consider several different scenarios. For example, COLHOUN and ADAMSON (1992), COLHOUN *et al.* (1992), MABIN (1992), MORIWAKI *et al.* (1992a) and IGARASHI *et al.* (1995a, b) suggest that ice thickness and extent in East Antarctica during the Last Glacial Maximum were very much less than has been hypothesized by HOLLIN (1962), HUGHES *et al.* (1981) and STUIVER *et al.* (1981). However, there need to be much more definitive age constrains of regional glacial histories during the Pleistocene. Present constraints are sparse due to the small

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amounts of materials suitable for dating (MORIWAKI *et al.*, 1992b)

In the Mt. Riiser-Larsen area, East Antarctica, there is a thick glacial drift that is interbedded by a thin silty or clayey layer (the Richardson Clay, HAYASHI, 1990; AKIYAMA *et al.*, 1990) The relative age of these deposits has been discussed in terms of the local glacial history; however, neither the till nor the clay has been quantitatively dated yet Ages related to glacial deposits obtained by various dating methods would be of great help in interpreting the regional glacial history. For this reason we will report on accelerator mass spectrometry (AMS) radiocarbon ages of organic materials in the thin silty or clayey layer and a precipitate in the thick glacial drift, and as well on thermoluminescence (TL) dating of the latter

2. Samples and Experiments

To the south-east of Richardson Lake in the Mt. Riiser-Larsen area, the thick till deposits are incised by an ephemeral stream On the wall of the channel we can observe them and an interbedded varved deposit, the Richardson Clay (HAYASHI, 1990, AKIYAMA *et al.*, 1990).

Samples were collected from the outcrops at Loc. 1 and Loc. 2 along the channel (Fig. 1). Sample No 1 of Loc. 1 for ^{14}C dating consisted of organic material from the lower part of the Richardson Clay. The maximum ^{14}C age detection by AMS measurement has been extended to about 60 ka, though the capability largely depends on the ^{14}C background at measurement (*e.g.*, NAKAMURA and NAKAI, 1988, IGARASHI *et al.*, 1995a, b). Therefore, the samples for ^{14}C ages were dated by AMS measurement Sample

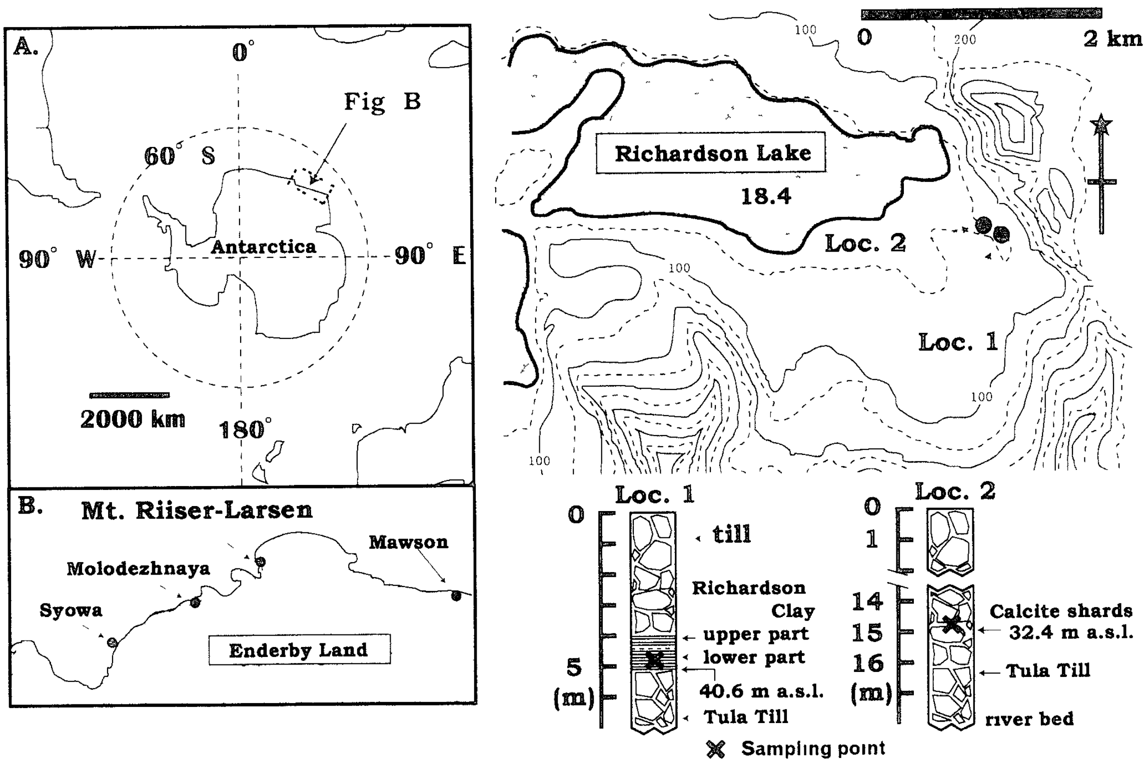

Fig 1 Location map of sampling sites and characteristics of materials

Fig. 2 The thick till deposits (Tula Till) at Loc 2 of Fig. 1

Fig 3. A thin white coating on a rock in the Tula Till at Loc. 2.

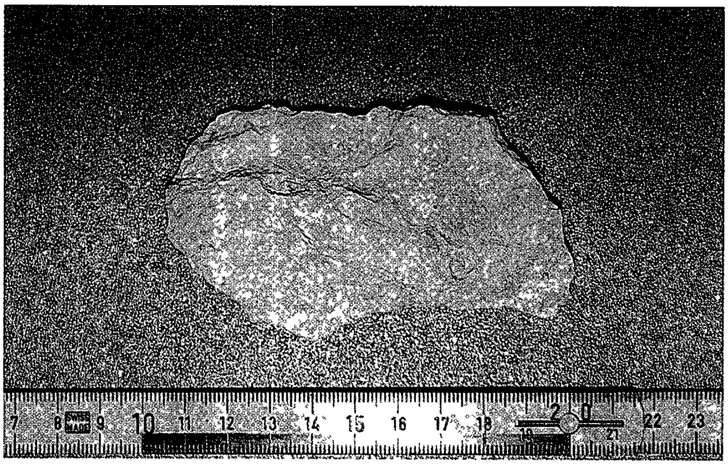

Fig. 4. The calcite of Sample No 2, a thin white coating on a rock, in the Tula Till at Loc 2

No 2 of Loc 2 for AMS ^{14}C and TL dating was a thin (about 4 mm) white coating on rocks in the till (Figs 2, 3 and 4) Similar materials occur as white coating at similar depth at some places around Loc 2 Both the chemical analysis and X-ray diffraction data identify the materials as calcite with low contents of aragonite and quartz (KOEZUKA, personal communication)

The dose-rate of external gamma and cosmic rays for TL dating was evaluated by on-site TL dosimetry at Loc 2. Furthermore, the dose-rate of external beta rays was estimated by the method of ICHIKAWA and HIRAGA (1988), assuming an attenuation factor (AITKEN, 1985). By the use of BELL's data (BELL, 1979), the internal dose-rate was calculated from U, Th and K_2O contents measured by gamma spectrometry, assuming the alpha effectiveness In all sample preparations for TL dating, in subdued red light to avoid bleaching effects, the procedures were carried out as follows: The calcite minerals were washed in distilled water, followed by treatment with 1 M HCl for 2 min to remove the outer layer which has a component of external alpha particle dosage (SHIMOKAWA *et al.,* 1992). Then they were gently crushed, followed by treatment with 1% HCl for 2 min to reduce spurious TL (WINTLE, 1978, KHANLARY and TOWNSEND, 1991) and sieved to 0 125–0 63 mm TL measurements were made with a Harshow TL reader A filter with 350–570 nm transmission characteristics was used to suppress spurious glows (NINAGAWA *et al.,* 1988) The peak intensity measurement was repeated 5 times. The amount of the sample for each measurement was the same (*ca.* 15 mg) Glow curves were recorded in an ambient nitrogen atmosphere at a heating rate of 10°C/s Artificial gamma irradiation was carried out with a ^{60}Co source. Samples for TL dating were irradiated in 8 steps to calculate an equivalent dose (ED) For supralinear correction, the second-glow growth characteristic was obtained by measurement of TL from portions which had been irradiated after 10 min annealing at 350°C, because the calcite to aragonite transition occurs at 400°C (JOHNSON and DANIELLS, 1960)

3. Results and Discussion

AMS ^{14}C ages corrected by the $\delta^{13}C$ values (NAKAMURA and NAKAI, 1988) in this study are 40250±1200 y BP for the varved organic clay (the Richardson Clay. Sample No 1) and 42570±670 y BP for the calcite sample (the Tula Till. Sample No 2) (Table 1) The ages are consistent with the stratigraphic positions of the samples. Because these ages are close to the limit of conventional ^{14}C analysis and therefore sensitive to the effect of contamination, they should be regarded as minimum ages Whether the reservoir correction (OMOTO, 1983, STUIVER and BRAZIUNAS, 1985) is required or not for Sample No. 1 is unknown, but if we need it, it may have not been much larger than the present value of 1300 years for calcareous marine species in the Southern Ocean (BERKMAN and FORMAN, 1996) Furthermore, the source of carbon for Sample No 2 is unknown If it was derived from subglacial or soil carbonate, its initial ^{14}C content may have been zero or quite low (*e.g* RIGGS, 1984, NAKAMURA *et al.,* 1991, NAKAMURA, 1995) and the 42 ka age may represent measurement blank or modern contamination

Figure 5 shows net TL glow curves obtained from the calcite sample (Sample No. 2) They have a plateau region of 200–250°C (Fig 6) Therefore, net intensities of

Table 1. Radiocarbon ages by accelerator mass spectrometry (AMS) in the Mt Riiser-Larsen area

	Sample No 1	Sample No 2
Sample name	Richardson Clay	Tula Till
Material	Organic sediments	Calcite
Lat (S), Long (E)	66°45′S, 50°40′E	66°45′S, 50°40′E
Analytical No	beta-107531	beta-106844
^{14}C age (y BP)[1)]	40110±1200	42250±670
δ^{13}C (per mil)	−16 3	−5 6
Corrected ^{14}C age (y BP)	40250±1200	42570±670

[1)] By using 5568 years as the half life of ^{14}C

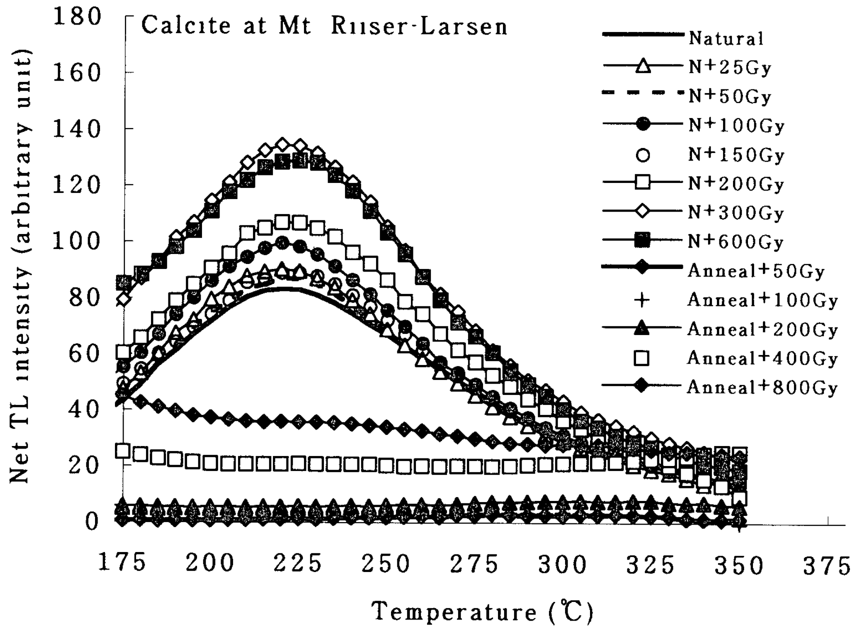

Fig 5 TL glow curves of the calcite sample (Sample No 2) from the Mt. Riiser-Larsen area.

the TL peak around 225°C are used for evaluating the equivalent dose (ED). Net TL intensities are plotted as a function of the radiation dose. Figure 7 shows the first and second growths of net TL intensities with artificial irradiation for the calcite sample. Though a TL growth curve of calcite is often fitted with a saturating exponential equation (*e.g.* FRANKLIN *et al.*, 1988; NINAGAWA *et al.*, 1988, 1992), we have obtained the ED by linear and extrapolative fitting (straight line) to the intersection with the x axis because the slopes of the first and second growths show similar linear features. As a result, the ED of the calcite sample for TL dating is 2065 Gy in this study. Taking 4 Gy of supralinear correction into account, *ca.* 2070 Gy is calculated as the paleodose.

The external dose-rate of gamma plus cosmic rays evaluated by on-site TL dosimetry was 2.77 mGy/year. External beta ray intensity was calculated to be 0.51 mGy/year by the method of ICHIKAWA and HIRAGA (1988), assuming 0.25 as the attenuation factor for a calcite shard 4 mm thick (AITKEN, 1985, p. 260) (Table 2). The contribution of the external alpha dose is neglected because the outer layer of the

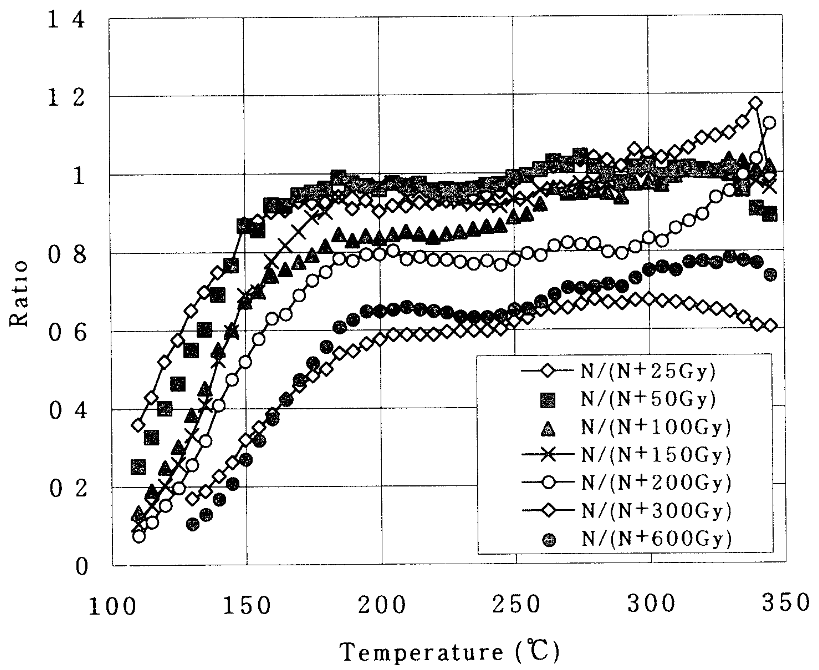

Fig 6 Plateau test for the TL dating of the calcite sample

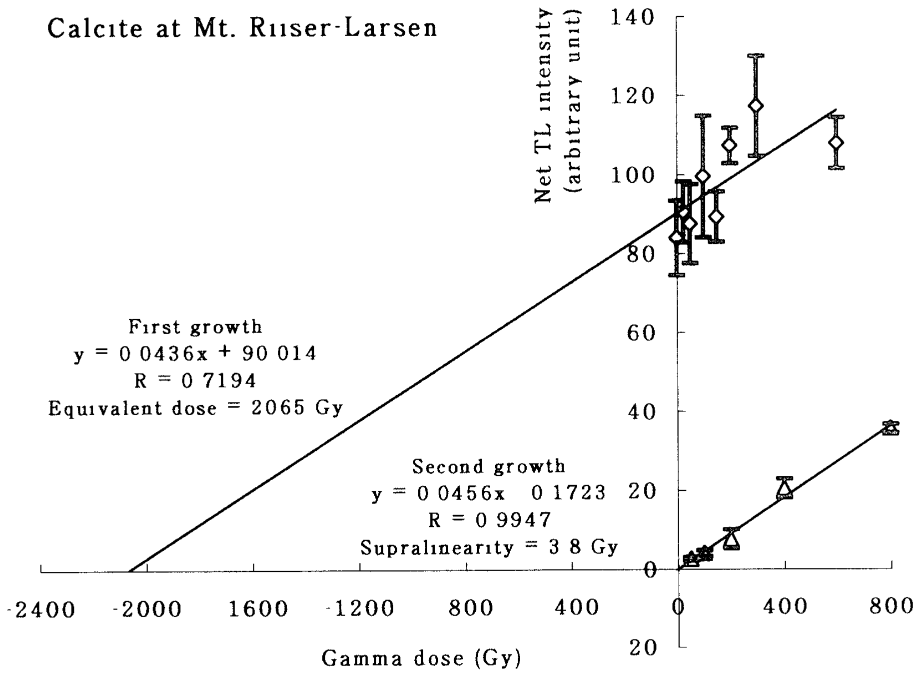

Fig 7 TL growth curve of the calcite sample
Intensities of TL peaks around 225°C were used for evaluating the age Error bars show ±1 standard deviation on individual measurement

calcite shard is removed by etching with HCl. However, a gamma spectrometry measurement shows that the U content of the calcite sample is extraordinarily high (Table 2) By the use of the BELL's data (BELL, 1979), the internal dose-rate is calculated from U, Th and K_2O contents, assuming secular equilibrium and 0.15 as the

Table 2. U, Th, K_2O contents of the calcite sample and the annual dose

		Content[1)]	α-ray (mGy/y)	β-ray (mGy/y)	γ-ray (mGy/y)
U	(ppm)	45.02	125.29	6.58	5.17
Th	(ppm)	3.17	2.34	0.09	0.16
K_2O	(%)	0.08	0.00	0.05	0.02
			127.63	6.73	5.35
Annual internal dose[2)]			=	25.87 (mGy/y)	
Annual external dose[3)]			=	3.28 (mGy/y)	
Total annual dose			=	29.15 (mGy/y)	

1) Measured by gamma spectrometry.
2) Calculated from the data of BELL (1979), assuming 0.15 as the alpha effectiveness k-value.
3) Including 2.77 mGy/y of γ-ray plus cosmic ray evaluated by on-site TL dosimetry and 0.51 mGy/y of β-ray evaluated by the method of ICHIKAWA and HIRAGA (1988), assuming 0.25 as the attenuation factor of beta ray for the calcite shard 4 mm thick.

alpha effectiveness k-value (AITKEN, 1985, p. 11). Therefore, taking the large internal dose-rate into account, 29.2 mGy/year is estimated as the annual dose.

The TL ages are obtained from the paleodose (the total amount of radiation damage accumulated in the past) divided by the annual dose (AITKEN, 1985). Therefore, the provisional TL age of the calcite sample (Sample No. 2) is assumed to be *ca.* 71 ka, though ideally a more adequate filter eliminating radiation with wavelengths above about 500 nm (*e.g.* Corning 5-60) should be used to remove interference by TL arising from entrained particles of old calcite (DEBENHAM and AITKEN, 1984; AITKEN, 1985; FRANKLIN *et al.*, 1988).

There is a discrepancy between the AMS ^{14}C and TL ages of the calcite sample (Sample No. 2). Furthermore, it is difficult to estimate a precise TL date from the data shown in Fig. 7 owing to the dispersion of the net TL intensities and effects of the inhomogeneous lumpy sample environments (stony till deposits) on the external dose rate. Taking the large annual dose of the calcite into accoount, however, it seems to be suggested that the TL age of calcite precipitate is not much older than the Last Interglacial Stage at the oldest estimate.

QUILTY (1992) indicates that a thin coating of aragonite firmly attached to basement rocks is widespread in the Vestfold Hills, East Antarctica. This coating can be regarded as a subglacial precipitate deposited in a closed system at a time when the Vestfold Hills was covered by an advancing ice sheet (AHARON, 1988). We think that the calcite in the Tula Till in the Mt. Riiser-Larsen area was deposited through a similar process, or through a reworking process after subglacial or subaerial precipitation. Therefore, we think that the Tula Till was overridden by an advance of the ice sheet lasting until after the Last Interglacial Stage. The till may have been deposited during this period.

Though there is a possibility that both of the AMS ^{14}C ages might be too young due to contamination by younger carbon or other factors, it seems hard to regard the true age of crystallization of the calcite as much older than the Last Interglacial Stage from the provisional result of TL dating In East Antarctica, ice thickness and extent during the Last Glacial Maximum are recently thought to have been very much less than was earlier hypothesized (*e.g.* COLHOUN and ADAMSON, 1992, IGARASHI *et al.*, 1995a), and the thick glacial deposits in the Mt. Riiser-Larsen area have been supposed to be correlatives of the late-Pliocene Pagodroma Tillite in the Amery Oasis in the Prince Charles mountains, and the Sirius Formation in the Transantarctic mountains (MORIWAKI *et al.*, 1992b) The result in this study, however, suggests that in a region like the Mt Riiser-Larsen area, where ice comes mainly from the coastal area around the Napier mountains, the possibility of a re-advance of the ice sheet and/or sedimentation of thick glacial tills during the late-Pleistocene should be taken into account

Acknowledgments

We are grateful to Prof K. MORIWAKI of the National Institute of Polar Research for his assistance in this study. We thank Prof. T. NAGATOMO and Prof S. HIRAGA of Nara University of Education for their kind cooperation in providing experimental facilities Thanks are also due to Dr T KOEZUKA of Nara National Cultural Properties Research Institute for the identification of the calcite minerals. We are indebted to two reviewers, Prof I TAKASHIMA of Akita University and Prof. M. HAYASHI of Shimane University, for their critical and constructive comments. Our particular thanks go to the geological party of JARE-38 for helping make the field work successful This study was partly financed by the Grant-in-Aid for Scientific Research from the Japanese Ministry of Education, Science, Sports and Culture (08680188 and 09780135).

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(Received March 23, 1998, Revised manuscript accepted July 2, 1998)